

Extraneural versus Intraneural Stimulation Thresholds during Ultrasound-guided Supraclavicular Block

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Background: A stimulation current of no more than 0.5 mA is regarded as safe in avoiding nerve injury and delivering adequate stimulus to provoke a motor response. However, there is no consistent level of stimulating threshold that reliably indicates intraneural placement of the needle. The authors determined the minimally required stimulation threshold to elicit a motor response outside and inside the most superficial part of the brachial plexus during high-resolution, ultrasound-guided, supraclavicular block.

Methods: After institutional review board approval, ultrasound-guided, supraclavicular block was performed on 55 patients. Patients with neurologic dysfunction were excluded. Criteria for extraneural and intraneural stimulation were defined and assessed by independent experts. To determine success rate and any residual neurologic deficit, qualitative sensory and motor examinations were performed before and after block placement. At 6 month follow-up, the patients were examined for any neurologic deficit.

Results: Thirty-nine patients met all set stimulation criteria. Median \pm SD (interquartile range) minimum stimulation threshold outside was 0.60 ± 0.37 mA (0.40, 1.0) and inside 0.30 ± 0.19 mA (0.20, 0.40). The difference of 0.30 mA was statistically significant ($P < 0.0001$). Stimulation currents of 0.2 mA or less were not observed outside the trunk in any patient. Significantly higher thresholds were observed in diabetic patients. Success rate was 100% after 20 min. Thirty-four patients had normal sensory and motor examination at 6 months. Five patients were lost to follow-up.

Conclusion: Within the limitations of this study and the use of ultrasound, a stimulation current of 0.2 mA or less is reliable to detect intraneural placement of the needle. Furthermore, stimulation currents of more than 0.2 and no more than 0.5 mA could not rule out intraneural position.

NEUROLOGIC dysfunction is recognized as a rare but potential complication of regional anesthesia. A number of related factors, such as obesity,¹ neurologic and metabolic diseases,²⁻⁴ neurotoxicity,⁵ and mechanical and ischemic injury, may contribute to the development of acute and/or chronic nerve damage. Intrafascicular puncture and injection as well as high intraneural pressure during injection have also been postulated as potential etiologic factors.⁶⁻¹⁰ Some authors recommend using an electrostimulation-guided technique to improve efficacy and decrease the risk of nerve puncture.¹¹ However, there is still controversy about the level of stimulating current required for a successful block at which the needle will remain a safe distance from the nerve to avoid injury.¹²

Current stimulation thresholds less than 0.5 mA have been recognized to deliver adequate stimulus to provoke a motor response while causing minimal discomfort to the patient.^{13,14} However, stimulating currents less than 0.5 mA do not guarantee the proximity of the needle to the neural tissue.¹⁵ Furthermore, animal studies have shown that in some cases with the needle intraneurally, a stimulation current of 0.5 mA or more was required to induce a contraction.^{16,17} Recently, in pigs, specific responses to nerve stimulation with currents < 0.2 mA have been shown to occur only when the needle tip was positioned intraneurally, but reports on humans are lacking.¹⁷

We hypothesized that the level of stimulating threshold outside the nerve differs significantly from the level inside the nerve and can be used to predict whether the needle tip is extraneural or intraneural. The position of the needle relative to the nerve was determined by ultrasound, and criteria have been set to adequately identify and ensure needle-to-nerve contact. To test our hypothesis, we determined the minimally required stimulation threshold to elicit a motor response just outside and inside the most superficial part of the brachial plexus during high-resolution, ultrasound-guided, supraclavicular block.

Materials and Methods

Fifty-five consecutive patients (American Society of Anesthesiology physical status 1 to 3) who presented for wrist or hand surgery, were enrolled in the study after

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Received from Department of Anesthesiology, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, and from the Division of Perioperative Care and Emergency Medicine, Department of Anesthesiology, University Medical Center Utrecht, Utrecht, The Netherlands. Submitted for publication April 29, 2008. Accepted for publication January 23, 2009. Supported by the Departments of Anesthesiology of the University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, and Linden Oaks Surgery Center, Penfield, New York, by the University of Rochester School of Medicine, Rochester, New York, by the University Medical Center Utrecht, Utrecht, The Netherlands, and by grant 017.005.12 from the Netherlands Organization for Scientific Research (NWO), The Hague, The Netherlands. All authors contributed equally to this work. The abstract of this study was presented at the Dutch Association of Regional Anaesthesia Meeting, Heeze, the Netherlands, February 8, 2008.

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institutional review board approval (Linden Oaks Surgery Center, Rochester, New York) and written informed consent. Patients whose age was greater than 17 yr were included in the study. Patients were excluded if the surgeon noted any sensory or motor abnormality in the neurologic examination of the patient's operative extremity. Demographic data, including age, gender, weight, and height, were recorded. Preexisting diabetes mellitus was also recorded. Relevant diabetic status included preexisting polyneuropathy defined as prediagnosed retinopathy or sensory or motor dysfunction of the lower limbs, insulin dependency, duration of disease after diagnosis, and fasting glucose and hemoglobin A1c level on admission.

Technique

A 22-gauge, 5-cm stimulating needle (B. Braun, Bethlehem, PA) attached to a nerve stimulator (model HNS 11; B. Braun) was used for all nerve blocks. All blocks were performed under ultrasound guidance by using an L25 probe resonating at 13 MHz in the multibeam mode (MicroMax; Sonosite, Bothwell, WA) or a Terason Platform (Terason Ultrasound, Burlington, MA) using an L33 probe resonating at 12 MHz in the multibeam mode. Each block was recorded in real-time from the ultrasound device to a digital tape recorder (GV-D900; Sony, San Diego, CA). At the same time, a nurse recorded the motion of the patient's operative extremity using a digital video camera (DCR PC1; Sony). After sedation with up to 2 mg of midazolam and 100 μ g of fentanyl, the brachial plexus was imaged in the supraclavicular fossa. The nerve stimulator frequency was set to 2 Hz, amplitude to 1.6 mA, and pulse width to 0.1 ms. Using a modified Plumb-Bob approach, the probe was placed in an oblique sagittal orientation in the supraclavicular fossa.¹⁸

Outside versus Inside

The interpretation of the data highly relies on the difference in location between outside and inside the nerve. The criteria for extraneural and intraneural needle tip location were defined as follows: (1) extraneural position (needle-to-nerve contact) when contact combined with slight indentation of the nerve wall was visualized by ultrasound,¹⁹ and (2) intraneural position (needle-in-nerve) when the needle tip was visualized adjacent to the nerve fascicles, which appear as distinct round- to oval-shaped hypoechoic nodules,²⁰ followed by distension and expansion of the nerve after injection of a small amount of local anesthetic.^{16,21-23}

The needle was inserted anterior to the probe and advanced in-line until the tip of the needle contacted the most superficial part the brachial plexus (fig. 1, A and B). After confirming the indentation of the nerve wall, the needle was drawn back just enough to undo the indentation, but still in contact with the nerve wall. If there was a motor response, the current was reduced to iden-

tify the threshold. If there was no motor response on contact, the current was increased until muscle twitches were observed, and threshold values were recorded. The needle was then advanced further into the confines of the trunk based on the intraneural criteria described earlier. The current amplitude was then decreased until the contraction vanished. The thresholds at which the contractions within the trunk vanished were recorded.

After recording the current threshold, intraneural position of the needle was further ascertained in all cases by injection of a maximum of 5 ml of local anesthetic (2.5 mg/ml bupivacaine, 10 mg/ml lidocaine, and 3 μ g/ml epinephrine) over approximately 15 s (fig. 1C). The needle was withdrawn immediately after confirmation of intraneural injection. Any injection, whether outside or inside the trunk was terminated when injection produced dysesthesia, or when the anesthesiologist felt unusually high resistance during attempted injection. With the stimulator turned off after repositioning the needle, a total of 20 ml was injected around the deeper parts of the brachial plexus. All injections were performed by one staff anesthesiologist with experience in ultrasound-guided supraclavicular block. Only the stimulation thresholds of the initially stimulated superficial part of the brachial plexus were included for final analysis (See video, Supplemental Digital Content 1, which demonstrates extraneural and intraneural needle tip position and injection, <http://links.lww.com/A1156>).

Image Analysis

The video and ultrasound recordings of each patient were spliced together on the same time line after the completion of the block using Adobe Premiere software (Adobe, San Jose, CA). Each time line (video and ultrasound recording) was reviewed independently by the author performing the block as well as a licensed sonographer experienced in musculoskeletal imaging and an anesthesiologist experienced in ultrasound-guided supraclavicular block. Only patients who fulfilled all criteria of extraneural and intraneural stimulation, including the confirmation by all independent experts, were included in the study.

Patients

All patients had a sensory and motor neurologic examination 20 minutes after completion of the block. Sensory function of the dermatomes C5-T1 was tested with a sharp 25-gauge needle in the skin distribution areas of the musculocutaneous nerve (lateral forearm), the median nerve (palmar surface of the thumb and palmar tip of the middle finger), the radial nerve (dorsum of the wrist), and the ulnar nerve (palmar surface of the fifth finger). A score of 1 was given if the patient could identify pinprick and 0 if the patient had no sensation or only pressure sensation. The muscular examination was done using the Medical Research Council scale (5 = full strength, 0 = no movement) by asking the patient to

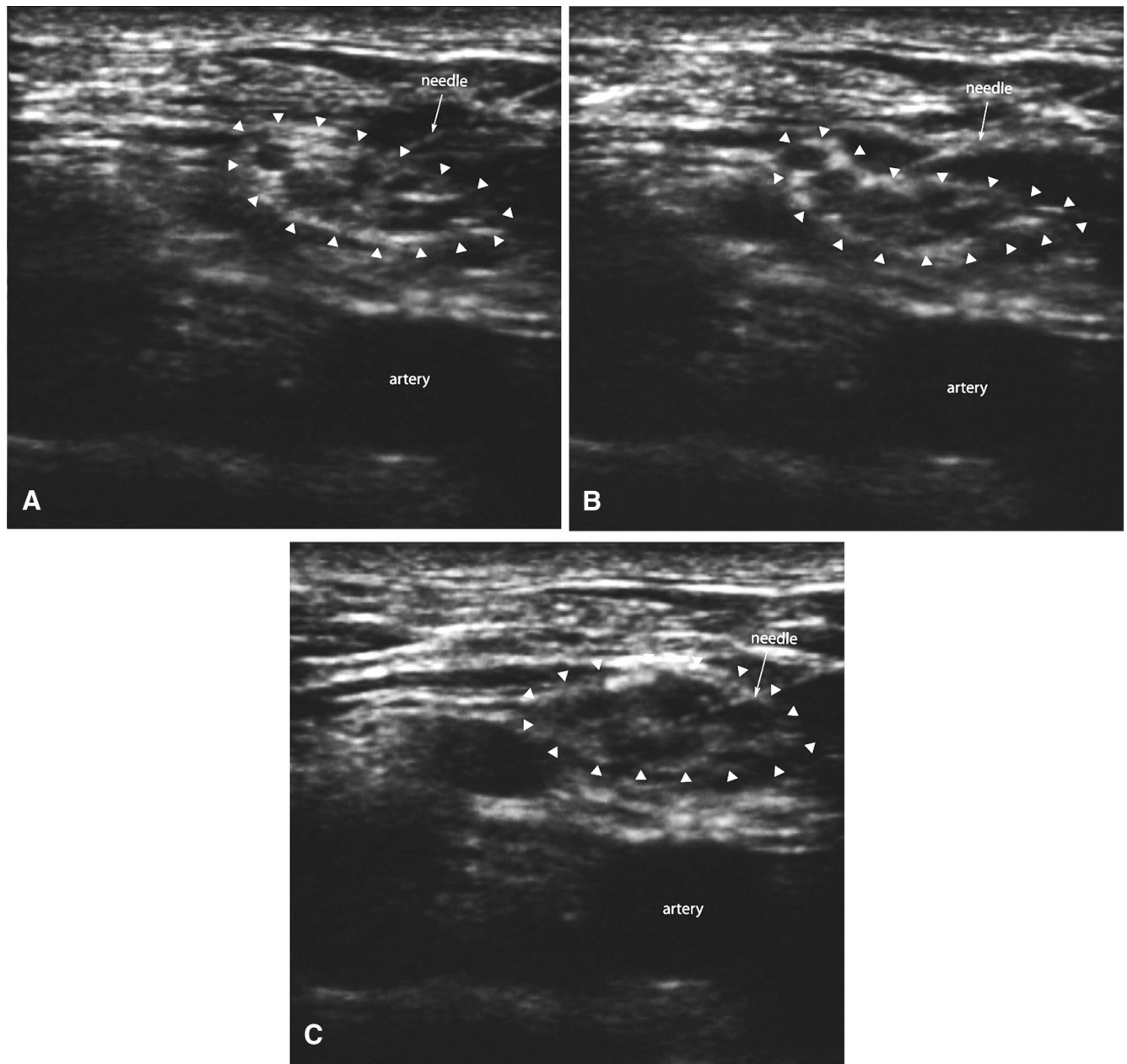


Fig. 1. Ultrasonographic overview of the neurovascular structures in the supraclavicular region: artery, subclavian artery; *arrow-heads* display the outer border of the brachial plexus. (A) Needle is against the wall of the brachial plexus. (B) Needle is touching and indenting the wall of the plexus (needle-to-nerve contact). (C) Intraneural injection after positioning the needle inside the plexus (needle-in-nerve).

perform the following maneuvers: elbow flexion (musculocutaneous nerve), flexion of the distal interphalangeal joint of the second finger (median nerve), extension of the wrist (radial nerve), and abduction of the third and fourth fingers (ulnar nerve).

All patients were called at home within 48 hours after the completion of the surgery to determine if they had any persistent numbness, weakness, or pain in the surgical extremity or the site of injection. All patients were seen by the surgeon within 72 h of completion of the surgery, at 3 weeks, and by the surgeon or her physician's assistant at 6 months. All patients had a neurologic

examination by the surgeon or her assistant at 72 h, 3 weeks, and 6 months.

Statistical Analysis

Data are presented as median \pm SD and interquartile range (IQR; 25%, 75%). Statistical significance of the difference in stimulation thresholds between inside and outside the trunk was performed using a two-tailed Wilcoxon signed-rank test. Analysis of differences between diabetic and nondiabetic patients was done using a Mann-Whitney U test. $P < 0.05$ were considered statistically significant. All the statistical analyses were per-

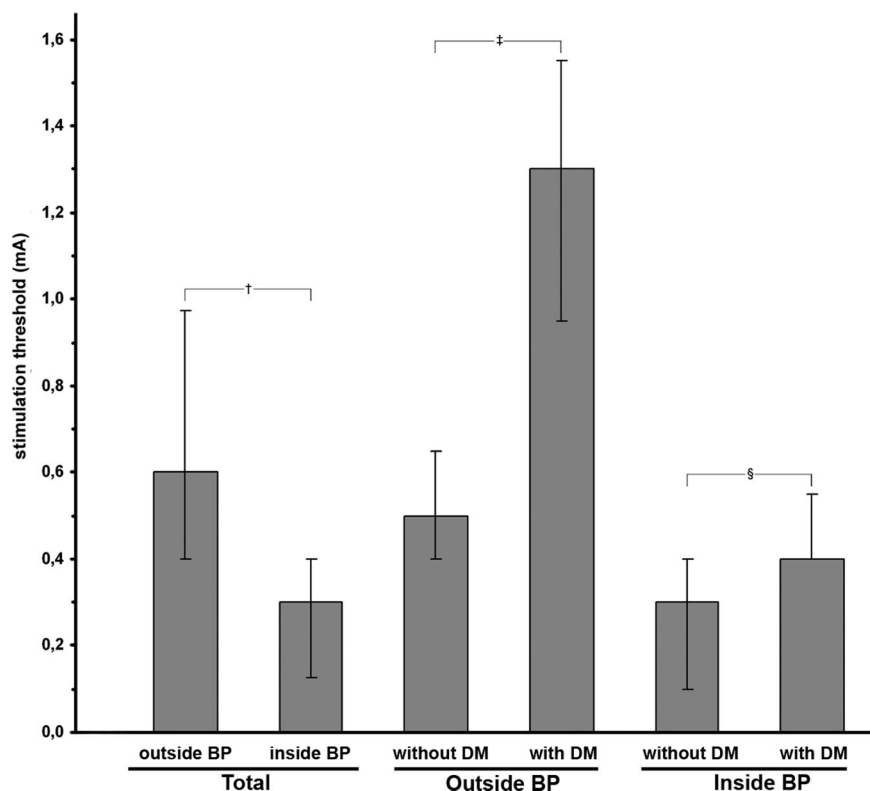


Fig. 2. Bars displaying the median and interquartile range (IQR; 25–75%) of minimum stimulation thresholds (mA) outside and inside the brachial plexus (BP) measured from the most superficial part of the BP in all patients (Total), diabetic patients (With DM), and nondiabetic patients (Without DM). DM = diabetes mellitus. † $P < 0.0001$; ‡ $P < 0.0001$; § $P < 0.005$.

formed using XLSTAT-Pro statistical software package (version 2007, Addinsoft, New York, NY).

Results

Thirty-nine patients (14 men, 25 women) met all criteria of stimulation for outside and inside the nerve, including complete agreement of the independent experts. Their median age and body mass index (BMI) were 54 ± 17.6 yr (range, 18–83 yr) and 29.5 ± 4.2 kg/m² (range, 21.0–37.9 kg/m²), respectively. Sixteen patients did not fulfill the inclusion criteria and were excluded. In all these patients, some local anesthetic needed to be injected to identify the position of the needle tip before stimulation. The median age and BMI of the excluded patients were 59.5 ± 18.6 yr (range, 19–81 yr) and 33.6 ± 3.7 kg/m² (range, 25.7–40.9 kg/m²), respectively. A significantly higher BMI was measured in the excluded patients compared to the included patients ($P < 0.001$).

The median \pm SD (IQR) stimulation threshold outside the trunk was 0.60 ± 0.37 mA (0.40, 1.0) compared to a value inside the trunk of 0.30 ± 0.19 mA (0.2, 0.4) (fig. 2). Table 1 shows the distribution of the stimulation thresholds categorized in four groups, *i.e.*, less than or equal to 0.2 mA, between 0.20 and 0.5 mA, between 0.50 and 1.0 mA, and more than 1.0 mA. Stimulation currents less than or equal to 0.2 mA were not observed outside the trunk in any patient. In 10% of patients, the stimulating threshold within the trunk exceeded 0.5 mA. Figure 3 illustrates the difference between the stimulating thresholds outside and inside the nerve for each individual patient. In 87% of patients, the stimulation threshold necessary to achieve a contraction decreased. In the remaining five patients, the stimulation threshold remained the same. In these patients, a value of 0.4 mA was measured in four patients, and a value of 0.3 mA in one patient for both outside and inside the trunk. Twenty-four patients (61%) experienced a difference greater

Table 1. Absolute Value of Minimum Stimulation Current Required to Elicit Muscle Contraction

| Current (mA) | All Patients (n = 39) | | Non-DM Patients (n = 32) | | DM Patients (n = 7) | |
|------------------------|-----------------------|----------|--------------------------|----------|---------------------|---------|
| | Out (%) | In (%) | Out (%) | In (%) | Out (%) | In (%) |
| ≤ 0.2 | 0 | 14 (36%) | 0 | 14 (44%) | 0 | 0 |
| > 0.2 and ≤ 0.5 | 16 (41%) | 21 (54%) | 16 (50%) | 16 (50%) | 0 | 5 (71%) |
| > 0.5 and ≤ 1.0 | 16 (41%) | 4 (10%) | 13 (41%) | 2 (6%) | 3 (43%) | 2 (29%) |
| > 1.0 | 7 (18%) | 0 | 3 (9%) | 0 | 4 (57%) | 0 |

DM = diabetes mellitus; Out = outside the nerve; In = inside the nerve.

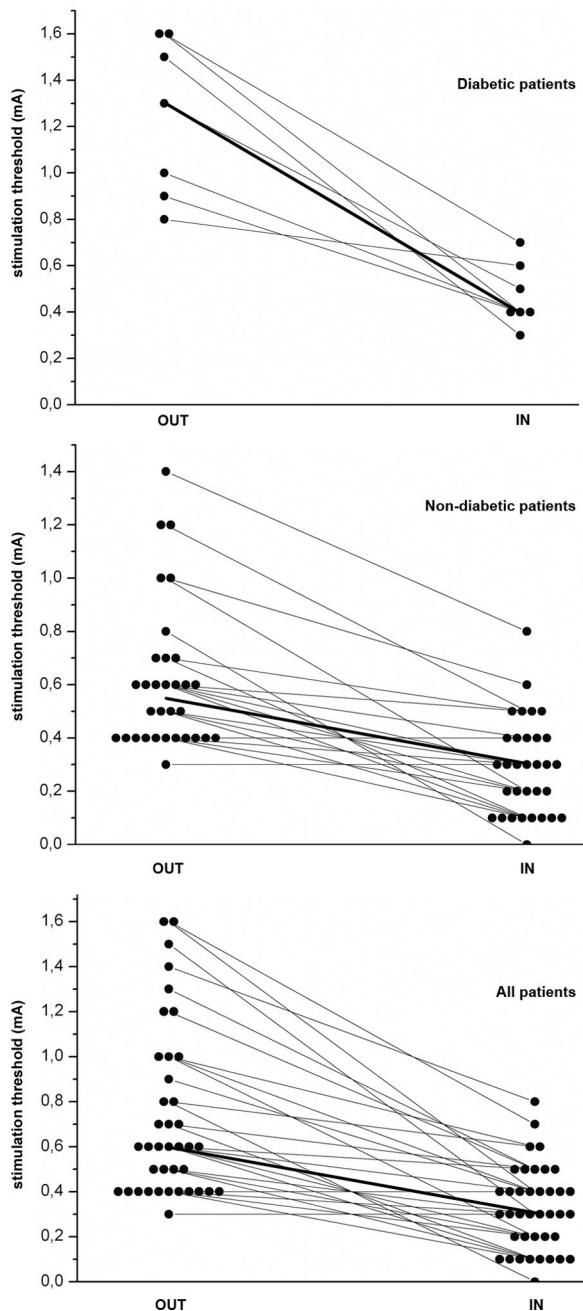


Fig. 3. Minimum stimulation thresholds (mA) outside and inside the nerve in each individual patient. Bold lines represent the median.

than or equal to 0.3 mA. The difference between the minimal stimulation current outside and inside was statistically significant ($P < 0.0001$).

All patients had akinetic, insensate limbs (motor = 0, sensory = 0) in all four nerve distributions at 20 min after blockade. In two patients, the anesthesiologist experienced high resistance to injection within the trunk. Both of these patients experienced pain during attempted injection. In these patients, the needle was withdrawn from the trunk, and a total of 10 ml of local anesthetic was infiltrated around the trunk without pain.

In all other included patients, injection proceeded easily without pain.

Diabetes Mellitus

Of the included patients, seven were prediagnosed with diabetes mellitus, of whom two were insulin-dependent. The remaining five patients took combinations of sulfonylureas (glipizide, glyburide, glimepiride), biguanides (metformin), or thiazolidinediones (rosiglitazone, troglitazone). Polyneuropathy related to the eye (fundoscopic examination) or foot (pinprick, brush, vibration, proprioception) was diagnosed in three patients, but none had any sensory or motor dysfunction in the upper extremities. The median (IQR) duration of the disease after diagnosis was 12 yr (5, 33). On admission, the median (IQR) fasting blood glucose and hemoglobin A1c levels were 8.1 mmol/l (4.6, 11.5) and 6.8% (6.7, 8.1), respectively. Overall, higher stimulation thresholds were needed outside ($P < 0.0001$) and inside the nerve ($P < 0.005$) compared to nondiabetic patients (fig. 2). In two patients, the difference of stimulation threshold between outside and inside was 1.2 mA. In 86% of diabetic patients, a difference equal to or greater than 0.5 mA was observed compared to 30% in nondiabetic patients.

Contraction Pattern

The contraction patterns associated with stimulation of the brachial plexus are presented in table 2. In 49% of patients (19 of 39), a similar contraction was seen outside and inside the trunk. In 74% (29 of 39), a typical pattern attributed to the superior trunk was observed, compared to 26% (10 of 39) attributed to the middle or inferior trunk.

Follow-Up

Three patients reported localized pain without radiation at the injection site at 48 h, which resolved gradually and spontaneously at 3 weeks without additional medication. None of them had any measurable sensory or motor defects postoperatively. Two patients reported numbness at 48 h. One of them who had an open reduction and internal fixation of his fifth metacarpal bone reported numbness in the fifth finger on the side of the surgical incision, which resolved at 5 weeks. This patient exhibited elbow flexion during extraneural and intraneural stimulation of his block. The other patient who had a palmar fasciectomy for a Dupuytren's contracture reported numbness in the palm of his hand, which resolved at 3 weeks. This patient exhibited elbow extension during extraneural stimulation and wrist extension during intraneural stimulation. Neither patient showed any sign of motor deficit. Both of the patients who had pain on attempted injection had normal exams at 72 h, 3 weeks, and 6 months. Thirty-four patients had normal sensory and motor examination at 6 months follow-up. The remaining five patients were lost to follow-up.

Table 2. Contraction Patterns of Extraneural Stimulation Followed by Intraneural Stimulation of the Most Superficial Part of the Brachial Plexus

| Extraneural Stimulation | n | Intraneural Stimulation | | | | | |
|-------------------------|----|-------------------------|-----------------|----------------------|---------------------|---------------|-----------------|
| | | Elbow Flexion | Elbow Extension | Pectoral Contraction | Deltoid Contraction | Wrist Flexion | Wrist Extension |
| Elbow flexion | 11 | 11 | | | | | |
| Elbow extension | 11 | | 6 | | 1 | | 4 |
| Pectoral contraction | 5 | 2 | | 1 | 2 | | |
| Deltoid contraction | 3 | | 1 | 1 | 1 | | |
| Wrist flexion | 3 | 2 | 1 | | | — | |
| Wrist extension | 6 | 1 | 3 | | | 2 | — |

Discussion

The current study is the first study comparing intraneural *versus* extraneural stimulation thresholds in humans. In 54% of patients, intraneural stimulation thresholds between 0.2 and 0.5 mA were observed. This is an interesting observation because many practitioners of regional anesthesia believe that the current level recommended for accurate current delivery while minimizing nerve injury or patient discomfort falls within this same range.^{14,24-26} A comparative study on pigs reported a 21% incidence of intraneural stimulation with muscle contraction when the minimum current ranged between 0.2 and 0.5 mA.¹⁶ This lower percentage compared to 54% found in our report may be explained by several factors such as physiologic differences between pig and human nervous tissue, dissected *versus* undisturbed anatomy, the number of subjects in each study, and differences in techniques. However, in both investigations, in a considerable percentage of subjects, intraneural needle placement could not be reliably differentiated from extraneural placement when a pulse duration of 0.1 msec and stimulation threshold greater than 0.2 and less than or equal to 0.5 mA was applied.

None of the stimulation thresholds outside the trunk were 0.2 mA or less. Thus, a contraction with a stimulation threshold of 0.2 mA or less with a pulse duration of 0.1 ms appears to be a reliable predictor of intraneural needle position in patients with normal sensory-motor examination. Recently, in pigs, Tsai *et al.* found similar stimulation thresholds for intraneural position of the needle.¹⁷ However, clinicians should not assume that the same results will be observed with different needles or stimulation generators or at other sites of the brachial plexus. The inconsistency of eliciting a motor response with electrical nerve stimulator has been shown by Urme and Stanton.²⁷ A sensory response after needle contact with a nerve may not always be accompanied by a motor response, which indicates some degree of insensitivity with the nerve stimulation technique.

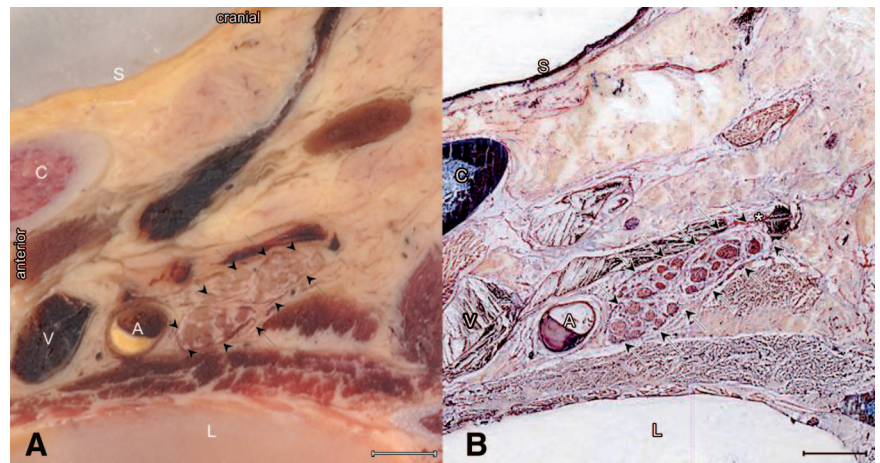
In the subgroup of patients with diabetes mellitus, higher stimulation thresholds were needed outside as well as inside the trunk compared to patients without diabetes mellitus. This difference is statistically significant, but the small number of the diabetic patients included in this study

necessitates caution if the findings are to be implemented in daily practice. Although higher stimulation thresholds to elicit motor responses in diabetic patients have also been reported in case reports,²⁸⁻³⁰ its routine application remains to be elucidated in a larger group of patients. The underlying mechanism remains unclear, but it involves a progressive impairment of sensory and motor function.³¹ In addition, studies indicate that patients with diabetes mellitus experience progressive decreases in nerve conduction velocity and amplitude in sensory and motor nerves.³²

An important limitation of the study is the exclusion of 29% of cases, which limits the interpretation of the findings to the general population. This may be attributed to both technical and patient-related factors. Technically, it is not always possible to reliably identify nerves with ultrasound. In a recent review, it was concluded that "... most ultrasound-guided clinical studies reported problems with obtaining satisfactory nerve images in some of their patients."³³ In a recent study, the supraclavicular brachial plexus was not adequately imaged in 21% of the patients.³⁴ With regard to the patient characteristics, the excluded patients were older and showed a significantly higher BMI than the included patients, challenging the reliability of ultrasound in detecting the exact location of the needle tip in these patients. This has also been reported for ultrasound-guided interscalene block.³⁵

Despite the methods we used to ascertain the location of the needle tip, two important findings may suggest that ultrasound may not always adequately determine the location of the needle tip as "inside" or "outside" the nerve. First, the fact that 23% of subjects (n = 9) required stimulating currents 0.5 mA or higher to acquire a motor response despite the needle tip being (presumably) inside the nerve may suggest an unreliable determination of needle location. Thus, it is possible that the observed differences in stimulation thresholds were caused by some uncertainty regarding the exact position of the needle tip. However, we consider this unlikely because our findings are in keeping with earlier studies.^{16,17,34} Second, the fact that 51% of stimulations did not demonstrate similar motor responses when stimulating outside *versus* inside the nerve further suggests an

Fig. 4. (A) A cross-sectional overview of the anatomy of the brachial plexus in the supraclavicular region (sagittal plane) from a 63-yr-old female cadaver with end-stage kidney disease (body mass index [BMI] 25.9 kg/cm²) (B) Histologic overview of the same plane. A = subclavian artery; V = subclavian vein; c = clavicle; S = skin surface; L = lung; *arrowheads* indicate the epineurium, which refers to the outer border of the brachial plexus. * The most superior part of the brachial plexus. Note that identification of individual trunks is visually difficult. Scale bar = 10 mm.



unreliable (and variable) determination of needle tip location.

However, the different motor responses outside and inside the nerve may also be related to the anatomic configuration of the nerve. More than 50% of the brachial plexus in the supraclavicular region is composed of fat and connective tissue.³⁶ This implies that the local tissue environment outside and inside the nerve may differ substantially, and thus the electrical current conduction characteristics of the tissue. Moreover, the distribution of neural tissue inside may further affect electrical current conduction. Connective tissue around the nerve may conduct the current in a different manner than the nonneural tissue inside the nerve. Furthermore, peripheral nerves are a heterogeneous mix of sensory and motor fascicles.³⁷ As the needle pierces the epineurium, the nerve often begins to rotate and compress.²⁰ The final position of the needle within the nerve may lie next to a different fascicle compared to the outside stimulation. Finally, no difference of stimulation current was observed between outside and inside the nerve in 13% of cases. The aforementioned reasons for the poor correlation of the contraction patterns could also apply for this observation.

The validity of high-resolution ultrasound in positioning the needle at the desired location, *e.g.*, directly adjacent to a nerve or even inside the nerve, has been shown to be high, as reported in other regions.^{19,38} Eichenberger *et al.* have shown that 33 of the 37 needle tips were located at the exact target point.³⁸ Sauter *et al.* have successfully implemented high-frequency ultrasound in the study of stimulation thresholds and different distances to the nerve to obtain motor responses.¹⁹ Needle tip visualization and indentation of the nerve wall were described as indicators for needle-to-nerve contact.¹⁹ The question remains regarding which layer is being contacted and indented. One generally assumes that the most outer border of the nerve is constructed of epineurium. In both anatomical and histologic examination of the trunks in the supraclavicular area, the

epineurial layer is easily identified (fig. 4). It is arguable whether this layer represents a continuation of the prevertebral and anterior and middle scalene muscle fascia. However, by puncturing this immediate outer layer, an opening is created into the inner environment of the nerve or trunk. Inside the trunk, this space is filled with fat and connective tissue surrounding the perineurium, which accounts for 52% of the brachial plexus cross-sectional area.³⁶ The perineurium encapsulates bundles of nerve fibers and is referred to as the actual nervous tissue or nerve fascicles. On ultrasound, the nerve fascicles appear as distinct round- to oval-shaped hypoechoic nodules.^{20,39} It was found technically feasible to place the needle tip adjacent to these nodules, thus assuming an intraneural position of the needle tip, although its validity needs to be confirmed in future investigations. In our study, we used the injection of small amounts of local anesthetic followed by the characteristic distension of the nerve, both described as indicators for intraneural injection,^{16,21-23} as final verification. Only patients in whom all experts agreed upon extra and intraneural position of the needle were included; therefore, we believe that our data are reliable in this respect.

In the included patients, measurements were done in the most superficial part of the brachial plexus. It is tempting to say that this is actually the superior trunk. Recognizing the superior trunk in the supraclavicular region provides some difficulties due to the technical limitations,⁴⁰ individual variability,⁴¹ and the close relationship between the trunks. This is best seen in figure 4, where the trunks have been formed in the supraclavicular region but are difficult to demarcate individually. The observed contraction patterns demonstrate that, under ultrasound guidance, the most superficial part of the plexus is not always the superior trunk. In fact, a typical pattern attributed to the superior trunk was observed in only 74%. This indicates that the cords have already been formed in the cases where a middle trunk response-type was found. It may also indicate that the tip of the needle was

advanced through the superior trunk into the confines of the middle trunk. Nonetheless, whether the stimulation threshold was measured from the superior or middle trunk, the observed differences remain reliable because stimulation of either trunk occurred intraneurally.

Two patients reported numbness postoperatively, which would account for a short-term injury rate of 5%. The relation between both injuries and the technique of nerve block is arguable. For confirmation of the intraneurally placed needle tip, a small amount of up to 5 ml of local anesthetic was injected. This could increase the risk of (short-term) injury. If associated with the nerve block itself, this rate could be regarded as high. However, in one patient, the numbness in the fifth finger was closely related and demarcated by the surgical incision side which makes it unlikely that the origin of the numbness was related to the technique of the nerve block. Furthermore, the second patient showed numbness of the palm after a palmar fasciectomy. The rate of nerve injury after fasciectomy in the surgical literature has been reported to be between 1.5% and 7.8%.^{42,43} In light of the surgical site and the incidence of nerve injury in the surgeon's hands, it is likely that the numbness is related to the surgery rather than the nerve block. An additional argument favoring this assumption is the fact that both patients showed a muscular contraction after intraneural placement of the needle that was not in the same sensory distribution area of the numbness. This observation would reduce the probability of the nerve block to cause nerve injury.

Recent observations in ultrasound-guided axillary block with visually confirmed intraneural injection of the local anesthetic showed that this injection does not invariably cause neural injury.²¹ However, this should not change clinical practice. The basic rule not to inject local anesthetics into the nerve remains. The limit of 0.2 mA should therefore be regarded as a safety level to detect intraneural needle position in electrostimulation-guided blocks of the brachial plexus. Further studies investigating the relation between intraneural injection and the development of neurologic damage are required.

In summary, clinically relevant differences in stimulation thresholds have been shown between outside and inside the nerve. Yet, these differences have to be interpreted in light of the possible inaccuracy of ultrasound to detect the exact location of the needle tip. Taking into account that the ultrasound was able to clearly detect the location of the needle tip in only 69% of cases, we consider stimulation currents of less than or equal to 0.2 mA reliable to detect intraneural position of the needle. Furthermore, stimulation thresholds greater than 0.2 and less than or equal to 0.5 mA could not rule out intraneural placement of the needle. Diabetic patients require higher stimulation thresholds both outside and inside the nerve to elicit a motor response.

The authors thank Ruud Stellema, M.D., Anesthesiologist, Department of Anesthesiology at the University Medical Center Utrecht, the Netherlands, for his constructive comments.

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■ ANESTHESIOLOGY REFLECTIONS

Draeger Pulmotor



Around 1908 the Draeger Oxygen Apparatus Company of Pittsburgh produced Pulmotors for resuscitating miners. The Pulmotor was designed as an automatic ventilator for pumping air or oxygen into the airways of victims of fire or mining accidents. By the 1910s, these devices were recommended for resuscitating electrocuted or drowned individuals. Rescue workers using Pulmotors were soon widely known as “Draegermen.” (Copyright © the American Society of Anesthesiologists, Inc. This image appears in the *Anesthesiology Reflections* online collection available at www.anesthesiology.org.)

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